

# On Structure, production, and market of bamboo-based panels in China

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**Abstract:** Since bamboo has the advantages of straight grain, beautiful color, high strength and toughness, and excellent abrasion resistance, bamboo-based panels have been widely used in the fields of vehicle, construction, ship building, furniture, and decoration to partly take the place of wood, steel, plastic etc in China. This paper briefly described the basic component units, including strip, sliver, and particle, of bamboo-based panel and pointed out that to design the structure of bamboo-based panels should follow the principle of symmetric structure, surface forming method, and structuring principle of equalizing stress. According to the processing methods and formation of component units, the authors classified the bamboo-based panels in China into 13 types and presented the manufacturing technique and uses of the bamboo products, such as plybamboo, bamboo flooring, and bamboo-wood composite products in detail. In the last part of the paper, much information were offered on the output, market, and selling prospect of each type of bamboo-based panels.

**Key words:** Bamboo-based panel; Component units; Structure; Production process; Market

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## Introduction

Bamboo, similar to wood, is a natural organism, composed of lignin, cellulose, hemicelluloses, etc.. Comparing with wood, bamboo, in particular, *Phyllostachys pubescens* M, has the advantages of moderate density, high strength and hardness, good abrasive resistance, low swelling after absorbing moisture, and splitting easily along lengthwise direction of a culm. Meantime, it also has a few shortages such as smaller diameter, hollow stem, sharp taper, obvious distinction at different grain direction, being attacked easily by insects and fungi, and cracking easily and so on. To utilize bamboo on a large scale, it is the best way to design and produce a series of bamboo-based panels with different structures and variable uses by taking advantage of bamboo property. The bamboo-based panels have advantages of large size, high strength, stabilization in shape and size after a series of procedures of spraying glue, laying up, and hot pressing. In addition, its parallel and perpendicular strength and property can be assigned according to different demands (Zhang *et al.* 1995). Through development of twenty years, Chinese bamboo-based panel has been increased not only in types of products but also in productivity (Zhang *et al.* 1999).

## Component units and structure principle

Bamboo has obvious properties at different grain direction. Its ratio of strength at parallel and perpendicular direction and the thickness of a panel can be obtained by reasonable design. In general, designing the structure of bamboo-based panel, we not only obey the principles of wood based panel, but also consider the characteristics of bamboo.

### Component Units

Since bamboo is a hollow cylinder with smaller diameter, thinner wall, its processing method is obvious different from that of wood. For example, bamboo cannot be processed into board by directly sawing or cut into bamboo veneer by a normal lathe or a plane. According to the structure and nature of bamboo, bamboo-based panels are made up of the following three basic component units:

**Bamboo strips:** Two kinds of strips are often used in the production of bamboo-based panel (Fig.1). One is called the soften-flattened strip. After softened in the condition of high temperature, arc bamboo pieces with certain length are flattened, and then planed at both outer and inner surfaces to form a strip of 60-80 mm in width and 3.0-7.0 mm in thickness with cracks on its surfaces, particularly on inner surface (Zhang 1988). The other is called saw-planed strip. It is obtained by sawing a culm into many strips of 20-30 mm in width and planing them into several thickness (Zhang *et al.* 2002).

**Bamboo sliver:** Since bamboo is easy to split along longitudinal direction, a narrow strip is split into several layers according to the thickness of bamboo wall to produce bamboo sliver (width 10-20 mm, thickness 0.8-2.0 mm) (Zhao *et al.* 2000).

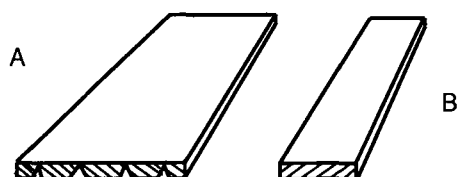
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**Bamboo particle:** Small diameter culms, irregular culms, and various residuals of bamboo processing can be roller-pressed, cut, and planed to form needle-shaped particle (Zhang *et al.* 1995).

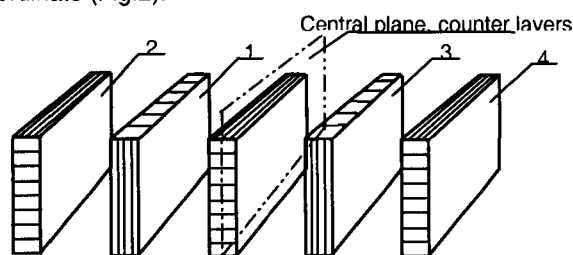


**Fig.1 Transverse sections of two kinds of strips**

A. Softened and flattened strip; B. Sawed and planed strip

### Symmetric structure principle

This principle must be complied with the production of various artificial boards. It means that the each side components such as species, grain direction, moisture content along the center layer of cross-section of the board must be coordinate each other. Only under such conditions, the stresses locating at two sides of the center layer are equal during process and use. Although the moisture content in the board gives birth to change, it cannot result in deforming and cracking of board owing to this symmetric structure (Zhang *et al.* 1995). In the concrete, for a plybamboo board, the thickness of bamboo strips, layers, ratio of parallel and perpendicular layers at two sides of center layer should be coordinate (Fig.2).



**Fig.2 Central plane and counter layers of five-layer plybamboo**

(1 and 3 symmetry, and 2 and 4 symmetry)

### Surface forming method

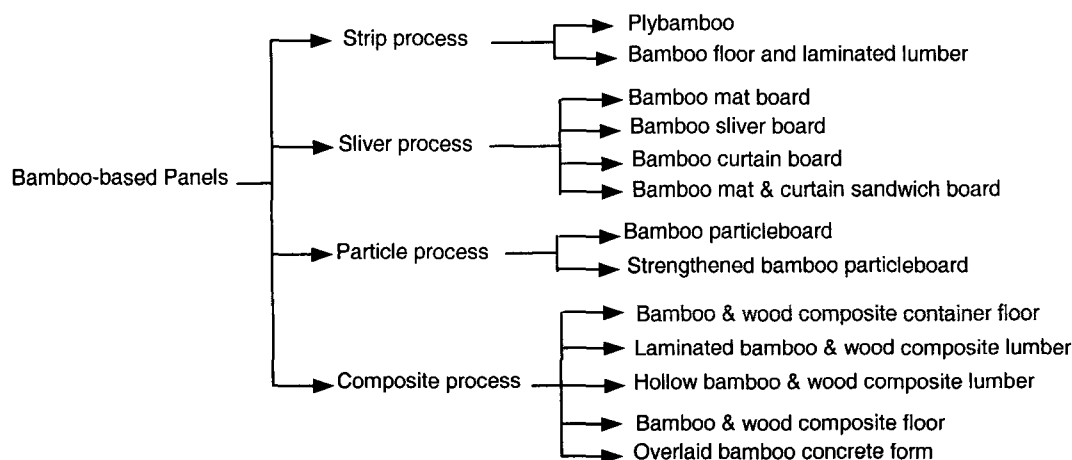
Since the strength of bamboo wall gradually decreases from outer layer to inner layer, we place the outer portion of the wall on board surface to enhance the strength and abrasive resistance of bamboo board such as plybamboo, bamboo curtain board, and bamboo flooring. Bamboo based-panel is usually used as engineering material, thus the largest stress appears at the surfaces when it is loaded.

### Structuring principle of equalization stress

This principle is mainly used to design composite board of bamboo and wood. Usually, when a board is loaded, the dominating bending stress takes place on its surfaces, and the maximum shear stress exists in the central layer of inner material. To enhance the integrated strength of a board, depending on the distribution of stress, we should select parallel bamboo strips as the surface material and wood board or veneer as the inside material that is placed across each other or paralleled. Meantime, we should lay thin wood boards or veneers near the central layer, or make a full superposition of central layer and wood so as to strengthen the power of shearing resistance. By this way the composite board of bamboo and wood is almost equal to bamboo boards in strength and abrasive resistance. Furthermore, this composite board is lower in cost and density than that of bamboo-based panels, and easy to nail as well (Sun 1999).

### Classifications and processing of main bamboo based panels

Now many kinds of bamboo-based panels have been produced in China, however, only more than ten types are widely utilized and produced. By processing method, bamboo-based panels can be classified into the following types (See Fig.3) (Zhang *et al.* 1999).



**Fig.3 The classification of bamboo-based panels according to processing method**

### Bamboo-strip product

The thick strips are processed by using bamboo culm at first, and then manufactured into bamboo board in accordance with the plywood procedure in production. The processing method of strip can be divided into soften-flattened way and saw-planed way.

**Plybamboo made in soften-flattened way:** Bamboo culm is firstly softened and flattened into pieces with the width of 60-120 mm (Jiang, 1995), after then the pieces are laid up and hot pressed to make plybamboo according to plywood procedure (Zhang 1989). The flow chart is shown in Fig.4.

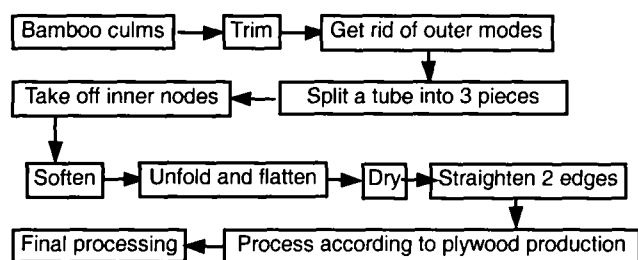


Fig.4 The flow chart of making plybamboo in soften-flattened way

Plybamboo is an excellent outdoor engineering material with the advantages of large and stable size, high strength, no deformation, etc.. Two adjacent layers of strips are laid up across each other after spreading phenol formaldehyde (PF) resin. Most of plybamboo are made up of 3 layers of strips and need a large amount of glue ( $40 \text{ kg} \cdot \text{m}^{-3}$ ). Its density is 0.80-0.85, MOR// (modulus of rupture along parallel direction) is more than 90 MPa; MOR $\perp$  (perpendicular direction) over 40 Mpa (Fig.5) (Zhang 1989). The advantages of making plybamboo are that we can make full use of the thickness of bamboo wall and the characteristics of easily forming the production line of machinery. The utilization rate of bamboo for plybamboo production reaches 30%-35%, but its investment is larger than that of other bamboo boards.

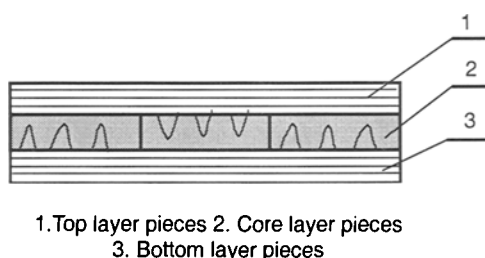


Fig.5 Crosscut sketch of plybamboo form

Plybamboo has been successfully used as the platform floor of truck and the floor of bus in Nanjing Automobile Group Company, No.1 Automobile Group Company, and No.2 Automobile Group Company in China during past 20

years. At present, there are more than 20 factories producing plybamboo in southern China such as Jiangxi, Fujian, Zhejiang, Anhui, Hunan, Hubei, Jiangsu, and Sichuan provinces.

**Bamboo flooring and laminated bamboo lumber made in saw-planed way:** Bamboo flooring is made up of planed strips with the same width and thickness. Firstly, the planed strips are laid up at parallel direction, and then hotly pressed at both level and vertical. The process flow diagram is as follows (Fig.6) (Zhang *et al.* 2002).

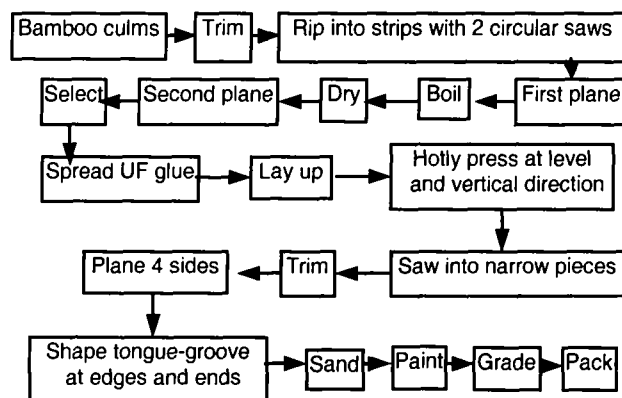


Fig.6 The process flow diagram of bamboo flooring and laminated bamboo lumber made in saw-planed way

The process of laminated bamboo lumber is similar to that of bamboo flooring except for the process of finish. After hot pressing, the lumber is edged and sanded. This board is suitable for the making furniture and the decorating house (Fig.7). Bamboo flooring and bamboo laminated lumber as refined indoor decorating products show the elegant appearance and the unique beautiful feeling. Bamboo flooring has been developing in the past several years. The technique and quality of production are strictly controlled. In addition, the production needs fresh and large diameter bamboo culms. Though the utilization rate of bamboo material is quite low (20% or so), bamboo flooring and bamboo laminated lumber are the profitable products and have a good market prospect. Up to now, more than 100 bamboo-flooring factories have been founded in bamboo forest areas of southern China.

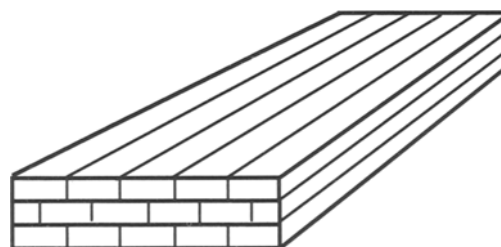


Fig.7 Laminated bamboo lumber

### Products made of bamboo sliver

The process takes full advantage of the bamboo characteristic of easily splitting along the parallel direction to split the narrow strips into several thin slivers (thickness 0.8-2.0 mm, width 10-20 mm).

**Bamboo-mated board:** Sliver is woven into mats at first. After dried, mats are dipped in PF adhesive, removed moisture, laid up and hotly pressed into a board that was composed of 2-5 layer mats. It is usually used as packing material or the covering board of railway box wagon. A few of thick boards are applied in the construction concrete form and the platform floor.

The procedures of splitting and weaving in the production are normally scattered in farmer houses. Farmers can make this kind of bamboo board in their spare time by simple hand tools. In addition, small diameter bamboo culms can be utilized. Thus sufficient raw material can be used to produce the bamboo mat (Zhang *et al.* 1995).

The factory of bamboo mat board is suitably founded in the underdeveloped areas in which there are many species of smaller bamboo and cheap labor. In China, there are many small bamboo-mated board factories in Sichuan, Hubei, and Zhejiang provinces.

**Bamboo-sliver board:** Dried slivers are firstly dipped in PF adhesive, and then dried in a kiln and laid up in parallel in a wooden frame, finally hot pressed to form products.

Since all slivers must be dipped in glue, and hotly pressed in very high pressure. The density of bamboo-sliver board is more than 1.0. In addition, all slivers are arranged at parallel direction, thus bamboo-sliver board has a higher parallel bending strength ( $MOR \geq 100$  Mpa) and the perpendicular strength is relatively low (Zhang *et al.* 1995; Ye *et al.* 1997).

At present, the sliver board of narrow shape (width  $\leq 300$  mm) is widely used as the platform floor of truck model "East Wind 141", the floor of railway box wagons, and the railway pad board under a central tray, etc.. There are approximate 10 factories in China, distributing in Zhejiang, Jiangxi, Hunan, and Hubei provinces (Zhang *et al.* 1995).

**Bamboo-curtain board:** Bamboo curtain, made up of slivers woven with cotton thread in parallel, is a component unit of the board. Dry curtains are dipped in PF glue, then dried, laid up and pressed into board. If the surface curtains are fine, it will be a good board with the excellent appearance after sanded and has high strength and stiffness. A variety of products can be developed by reducing the thickness of surface slivers, changing lay up, and compounding with other materials. For example, this board has been assembled at many sample trucks as platform floor replacing for plybamboo for its nice and flat figure and high strength (Fu *et al.* 1995).

**Bamboo concrete form:** Bamboo concrete form is also called "bamboo mat and curtain sandwich board". Its two surfaces are the mats filled with PF adhesive, and the core is made up of curtains that across laying up each other. If necessary, the surface of mat can be covered with im-

pregnated paper to form overlaid bamboo mat and curtain board. In general, many factories make the products by purchasing mats and curtains made by farmers. This board has been a dominant product in construction concrete form market of China. There are over 30 factories making this product that mainly distributed in the southern China such as Hunan, Hubei, Jiangxi, Zhejiang, and Jiangsu (Zhang *et al.* 1995; Han 1997).

### Bamboo-particle products

**Bamboo particleboard:** Bamboo particleboard is made from small bamboo culms, top parts of moso bamboo (*Phyllostachys pubescens* M), irregular culms, and processing residues according to the principle of wood particleboard. Except the procedures of particle preparation and spreading PF adhesive, the process is similar to that of wood particleboard. Making bamboo particleboard can sufficiently utilize bamboo resource. Normally, 1-m<sup>3</sup> product needs 1.3-t raw bamboo. Thus it is worthy to develop in the area with small diameter bamboo forest and in bamboo processing enterprises so as to enhance bamboo utilization efficiency (Zhang *et al.* 1998).

Bamboo particleboard with PF adhesive has higher MOR and MOE, and lower swelling rate after absorbing moisture, compared with wood particleboard. It has demonstrated a certain prospect in concrete form market.

**Intensive bamboo particleboard:** To enhance the mechanical properties of intensive bamboo particleboard, one way is laying bamboo curtains into the board, and the other way is to covered the surfaces of a piece of bamboo particleboard with bamboo pieces (Sun *et al.* 1995).

**Overlaid bamboo particleboard:** Two pieces of papers impregnated with PF or melamine adhesive are separately coated on two surfaces of bamboo particleboard so as to enhance surface gloss and decrease the absorption of moisture.

**Overlaid strengthened bamboo particleboard:** The surfaces of strengthened bamboo particleboard are coated with impregnated papers.

### Composite process of bamboo-wood

China is rich in bamboo resources and yield, and its annual output of bamboo correspond to 650 million m<sup>3</sup> wood. However, China is lack of sufficient supply of wood, and the bamboo output only serves as 6%-10% of total wood consumption yearly. Along with increasing of industrialized utilization of bamboo, bamboo culms, in particular, the large diameter culms have been obviously inadequate in China. The present price of bamboo culms is 5 times that of 1980s, whereas the price of wood, particularly the fast growing species, tends to decrease. The market competition of bamboo products is directly impacted. As a structure material, the surfaces of a board bear the main loads of bending and hitting. We can take advantage of a composite structure of bamboo-wood to replace the full bam-

boo board in consideration of the scientific reason of structure and process (Zhang *et al.* 1995; Yin *et al.* 1997). The following bamboo-wood composite products have been produced on a small scale now (Zhu *et al.* 1996).

**Bamboo-wood composite container floor:** It is made up of bamboo curtains, bamboo mats, and two pieces of impregnated papers that are placed on surfaces, and wood veneers used as a core of the board. This product has higher strength and stiffness that can meet the need of container floor, with properties as: density  $\leq 0.85$ , MOR  $\geq 80$  Mpa, and MOE  $\geq 10,000$  Mpa. It has been used in container floor on a batch (Zhang *et al.* 1997; Sun *et al.* 1995).

**Laminated bamboo-wood composite lumber:** Its surface material is composed of two thin curtain boards (thickness 3-4 mm) with high density, and its interior is formed with three layers of wood boards (thickness 10-15 mm). Compared with a full bamboo board, it has the advantages of high strength, good abrasive resistance, lower density, good holding nail, and low cost. Now this product has been in test on railway flat wagons.

**Hollow bamboo-wood composite lumber:** It consists of hollow wood frame in the core and bamboo curtain board on the surfaces, with light weight and high stiffness. This product is being tested as scaffolds in a shipbuilding factory (Zhang *et al.* 1997).

**Bamboo-wood composite floor:** Its surface is made up of planed thin bamboo strips, and the core is made up of Chinese fir board. This product with appearance of bamboo floor and the properties of wood becomes a promising product both in domestic and oversea market.

**Overlaid bamboo concrete form:** The plybamboo or bamboo curtain board that has been sanded into the same thickness is used as the core board, one layer of wood veneer and one piece of impregnated paper are coated on both top and bottom surfaces, and then hotly pressed to form a glossy product. This product is accurate in thickness, very smooth and glossy, and excellent in both strength and stiffness. It has been widely applied in such large concrete buildings as large bridge, overhead highway, etc..

### Market of bamboo-based panels

Since bamboo has the advantages of straight grain, beautiful color, high strength and toughness, and excellent abrasion resistance, bamboo-based panels have been widely used in the fields of vehicle, construction, ship building, furniture, and decoration to partly take the place of wood, steel, plastic etc. (Zhang *et al.* 1999).

### Structure material

Bamboo-based panel can be widely used as structure material such as platform floor of trucks and buses, concrete form, scaffold for ship building, etc., because its strength is higher than that of wood, toughness is better

than that of steel, and aging resistance is superior to that of plastic. In addition, it is easy to process and acceptable in price.

**Plybamboo for vehicle platform floor:** It is mainly used as the platform floor of trucks, buses, rail box wagons, and platform wagons. Many measures and investigations proved that plybamboo is much better in strength, shock resistance, and durability than that of wood. For example, the thickness of wood platform floor of light truck, middle truck, box wagon, and platform wagon is 25, 35, 50, and 70 mm, respectively, while using plybamboo as platform floor, the thickness of those products is reduced to 15, 22, 30, and 45 mm, respectively. Compared with wood platform floor, plybamboo platform floor shows the advantages of lower price, richer raw material resource, more convenience to be assembled, and more durability. More than 50 truck and bus factories have been using plybamboo as platform floor, and 10 railway factories use plybamboo as the platform floor of box wagon and platform wagon. The total amount of plybamboo demanded in China approximates to 100 000 m<sup>3</sup> yearly.

**Bamboo mat-woven board for inner top board of box wagon:** State Rail Department plans to build several thousand box-wagons each year, so the demand for this product reaches approximately 5 000 m<sup>3</sup> one year.

**Bamboo - wood composite for container floor:** Traditional container floor is made of a sort of thick plywood made from tropic hard wood. The property of plybamboo is similar to hard wood. A few companies in China had trailed for a long time in utilizing plybamboo to replace tropic hard wood, however the plybamboo cannot meet the requirement of the property of container floor, in particularly in MOE. The composite container floor of bamboo-wood, developed by Bamboo Engineering Research Center of Nanjing Forestry University, is made up of bamboo laid on surfaces and wood veneer that is used as the core layers of the board. It is a kind of composite board through the processing of laid up, hot pressing, and finish processing, and meets the need of container floor. At present, the container productivity in China is more than 1 000 000 TEU of standard container one year, and the demand container floor is estimated at 300 000 m<sup>3</sup> yearly.

**Concrete form:** it is a basic shaping board in construction. As more and more concrete engineering such as skyscrapers, cross bridges and highway etc. are constructing, the demand of concrete form is large in China. Traditional concrete form was made of wood board. The steel form, and wooden plywood were developed from 1960s to 1980s. Since 1990, various sorts of bamboo-based panels have been widely applied in construction for the advantages of large size and good stiffness. In particularly, the overlaid bamboo-based panel is easy to separate from concrete. Now bamboo-based panel concrete forms occupy one third in construction market. Approximately 100 factories produce various bamboo concrete forms, with the sum of productivity and selling 500 000 to 600 000 m<sup>3</sup> one year.

### Decorate material

Besides physical and mechanical properties being similar with hard wood, bamboo has the advantages of straight grain, white color, easy to bleach and dye etc.. It is an important decorates material.

**Bamboo flooring:** There are various kinds of flooring such as wood flooring, intensive composite flooring, and bamboo flooring etc., on the market of China, and the sum of demand each year is more than 100 million m<sup>2</sup>. Bamboo flooring, a new product, has appeared for 10 years in China. The process of bamboo flooring is more complex than that of wood flooring, and its technical requirement is stricter than that of wood flooring. This product showed more or less quality problems in most of factories in early 1990s. During the past several years, the process and equipment of bamboo flooring have been improved, and product quality keeps steady. It has been well accepted by foreign and domestic markets. It is counted that the productivity of bamboo flooring in 1999 reached 3 000 000 m<sup>2</sup>, of which 60%-70% were exported to Japan and Europe. It is estimated that the output of bamboo flooring will reaches 10 million m<sup>2</sup> in 2002.

**Laminated bamboo lumber:** Laminated bamboo lumber is a kind of large size board that is made up of bamboo strips with certain width and thickness. It has various thick products by changing the layers of strips laid up. Thick laminated bamboo lumber can be used as the post elements of bamboo furniture or decorate material, and the thinner ones can be used as the boards of bamboo furniture or decorate boards or lining material. The laminated bamboo strip lumber is a new product and began to be produced on scale, most of the products are exported to foreign countries.

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